Klinik für Zoo- Heim- und Wildtiere, Department für Kleintiere

der Vetsuisse-Fakultät Universität Zürich

Direktor: Prof. Dr. Jean-Michel Hatt

Evaluation of two miniplate systems and figure-of-eight bandages for stabilization of experimentally induced ulnar and radial fractures in pigeons (*Columba livia*)

Inaugural-Dissertation

zur Erlangung der Doktorwürde der

Vetsuisse-Fakultät Universität Zürich

vorgelegt von

Beatrice Miriam Bennert

Tierärztin

von Rosenheim, Deutschland

genehmigt auf Antrag von

Prof. Dr. med. vet. Jean-Michel Hatt, Hauptreferent

Prof. Dr. med. vet. Maria-Elisabeth Krautwald-Junghanns, Korreferentin

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Inhaltsverzeichnis

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Klinik für Zoo- Heim- und Wildtiere

Evaluation of two miniplate systems and figure-of-eight bandages for stabilization of experimentally induced ulnar and radial fractures in pigeons (*Columba livia*)

Although plate fixation has advantages over other fixation methods for certain indications, it is rarely used in avian surgery, especially in birds with a bodyweight below 1000 g.
Based on the results of the previous studies by Christen et al. (2005) and Gull et al. (2012), two miniplate systems were evaluated in 27 pigeons (*Columba livia*) divided in 4 groups (A, B, C and D) of 6 to 7 birds each. The left ulna and radius of the pigeons were transected and the ulna was repaired with a bone plate. The plate systems were used in combination with or without a figure-of-eight bandage for 10 days. In group A and B, an adaption plate 1.3 was applied without and with bandage; in group C and D a compression plate 1.0 was applied without and with bandage, respectively. Healing was evaluated with radiographs after 3, 14 and 28 days, a flight tests after 14, 21 and 28 days, and a macroscopic examination of the wing after euthanizing the animals at day 28. Fractures healed without bending or distortion of the plate in all 27 birds.
Without statistically significant differences 23 pigeons showed good or very good flight ability at the end of the study.
In conclusion, the adaption plate 1.3 and the compression plate 1.0 met the requirements for avian osteosynthesis and can be recommended for fracture repair of the ulna or other long bones in birds weighing fewer than 500 g.

Key words: miniplate, compression plate 1.0, adaption plate 1.3, fracture, osteosynthesis, ulna, radius, bird, avian, pigeon, *Columba livia*

Obwohl Frakturversorgung mit Verplattung anderen Methoden bei bestimmten Indikationen überlegen ist, wird sie in der Vogelchirurgie kaum eingesetzt, besonders bei Vögeln mit einem Körpergewicht von weniger als 1000g.

Ausgehend von den Resultaten früherer Studien von Christen et al. (2005) und Gull et al. (2012), wurden zwei Miniaturplattensysteme an 27 Tauben (*Columba livia*), die in 4 Gruppen (A, B, C und D) von jeweils 6 bis 7 Vögeln eingeteilt wurden, untersucht. Die linke Ulna und Radius der Tauben wurden durchtrennt und die Ulna wurde mit einer Knochenplatte fixiert. Die Plattensysteme wurden ohne und mit Kombination eines Achterschlingenverbandes für 10 Tage eingesetzt. In Gruppe A und B wurde jeweils eine *adaption plate 1.3* ohne und mit Verband angewendet; in Gruppe C und D wurde jeweils eine *compression plate 1.0* ohne und mit Verband angewendet. Die Heilung wurde mittels Röntgenbildern nach 3, 14 und 28 Tagen, Flugbeobachtungen nach 14, 21 und 28 Tagen sowie makroskopischer Untersuchungen des Flügels nach Euthanasie der Tiere nach 28 Tagen beurteilt. Die Frakturen heilten bei allen 27 Vögeln ohne Verbiegung oder Deformation. Ohne statistisch signifikante Unterschiede waren 23 Tauben zum Ende der Studie gut oder sehr gut flugfähig.

Fazit: Die *adaption plate 1.3* und die *compression plate 1.0* genügen den Erfordernissen für Osteosynthese beim Vogel und können zur Frakturversorgung der Ulna oder anderer Röhrenknochen von Vögeln, die leichter als 500g sind, empfohlen werden.

Schlüsselwörter: Miniaturplatte, *compression plate 1.0*, *adaption plate 1.3*, Fraktur, Osteosynthese, Ulna, Radius, Vogel, aviär, Taube, *Columba livia*

Evaluation of two miniplate systems and figure-of-eight bandages for stabilization of experimentally induced ulnar and radial fractures in pigeons (*Columba livia*)

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Abstract: Although plate fixation has advantages over other fixation methods for certain indications, it is rarely used in avian surgery, especially in birds with a bodyweight below 1000 g. Exceptionally small plating systems for these birds are required which are relatively expensive and difficult to insert. In addition it was shown that bending of these small plates frequently occurs. Based on the results of the previous studies by Christen et al.[1] and Gull et al.[2], in the present study 2 miniplate systems were evaluated in 27 pigeons (*Columba livia*) divided in 4 groups (A, B, C and D) of 6 to 7 birds each. The left ulna and radius of the pigeons were transected and the ulna was repaired with a bone plate. In group A and B, an adaption plate 1.3 was applied without and with a figure-of-eight bandage; in group C and D a compression plate 1.0 was applied without and with bandage, respectively. Healing was evaluated with radiographs after 3, 14 and 28 days, flight tests after 14, 21 and 28 days, and macroscopic examination of the wing after euthanizing the animals on day 28. Fractures healed without bending or distortion of the plate in all 27 birds. There were no major statistically significant differences between the treatment groups. At the end of the study, 23 pigeons showed good or very good flight ability. In conclusion, the adaption plate 1.3 and the compression plate 1.0 meet the requirements for avian osteosynthesis and can be recommended for fracture repair of the ulna or other long bones in birds weighing fewer than 500 g. The application of a figure-of-eight bandage might be beneficial.

Key words: fracture, osteosynthesis, ulna, radius, compression plate 1.0, adaption plate 1.3, bird, *Columba livia*

Introduction

Although plate fixation has advantages over other fixation methods for certain indications, it is rarely used in avian surgery, especially in birds with a body mass below 1000 g.[3] In larger birds, plating appears to be used regularly, because metal and acrylic plates are easily available in sizes that are useful for such animals, as reviewed in Gull et al.[2] Montgomery et al.[4] used a locking compression plate system to treat a comminuted tarsometatarsal fracture with delayed union after 1 month of external coaptation in a bald eagle (*Haliaeetus leucocephalus*); Dal-Bó et al.[5] treated a blue-yellow-macaw **(***Ara ararauna*) with an old mid-diaphyseal fracture of the left tibiotarsus successfully using a titanium miniplate 2.0 mm; and Sá et al.[6] stabilized a simple, complete, spiral-third fractured right tibia in a goose (*Anser anser*) with a miniplate.

In birds with a body weight below 1000 g, exceptionally small plating systems (i.e. miniplate systems < 2 mm) are required, which are relatively expensive and more challenging to insert. So far, none of the tested implants have proven entirely satisfactory for the use in small avian species.[1, 2, 7]

Christen et al.[1] used a maxillofacial titanium adaptation miniplate 1.0 mm to treat induced ulna and radius fractures in pigeons (*Columba livia*); all implates bent, and there was exuberant callus formation. The authors recommended the use of stronger and longer plates in a future study, because an increase in plate size and length may increase the strength of an implant and reduce the risk of fatigue failure. The hypothesis that longer plates may be more favorable was supported by findings in the study by Gouvêa et al.[7] evaluated the use of titanium miniplates in the treatment of experimentally induced mid-diaphyseal fractures of the right tibiotarsus in 30 pigeons. Although the forces acting on the pelvic limb differ from those acting on the thoracic limb, the most common complication in this study was also bending of the implants; no implant loosening was observed. Best results were seen in that study using the 1.0 titanium miniplate with 8 holes and a central spacer, resulting in bone healing within 27 days. Bending occurred in 20% of patients treated with the titanium miniplate with 8 holes and a central spacer compared to 60% with the titanium miniplate with 6 holes and a central spacer, and 40% with the titanium miniplate with 8 holes without a central spacer.

Based on the results of Christen et al.[1], Gull et al.[2] performed a study on ulnar fracture repair in pigeons using a longer 1.0 titanium miniplate (8 holes with a spacer) and compared it to a steel 1.3 adaptation plate. Bending occurred in all titanium miniplates. The steel plate was superior to the titanium plate with respect to bending; however, loosening of screws occurred. The authors concluded that not the length of the plate, but the stability of the plate material determines occurrence of bending. Regarding the risk of screw loosening, they recommended further trials with smaller drill bits and with screws having a smaller thread pitch to improve the system. In addition, the authors suggested the use of a figure-of-eight bandage postoperatively to improve healing.

Recently a steel compression plate system 1.0 has been marketed that includes screws with a thread pitch as proposed by Gull et al.[2] The aim of the present study was to evaluate this new plate in comparison with the 1.3 adaptation plate used by Gull et al.[2] for the stabilization of experimental ulna and radius fractures in pigeons. Additionally, the effect of a figure-of-eight bandage was tested. We predicted that fracture healing with less callus proliferation and better ability of flight could be achieved using a 1.0 compression plate compared to a 1.3 adaptation plate. Due to additional stability provided by a figure-of-eight bandage, an improved healing with either plate system was expected in birds receiving a bandage compared to those treated without a bandage.

Materials and Methods

The present study was carried out with 30 birds. All animal procedures were approved by the cantonal Animal Care and Use Committee (license number 143/2013). The animals were divided randomly into 4 groups of 7 pigeons each (A, B, C and D). Two additional birds served as control group with physiologic ability of flight. In group B 1 animal died. Pathological diagnosis revealed severe gout of the viscera and kidneys.

Animals were obtained from a private breeder. Prior to surgery, all birds were examined clinically and marked individually with coloured plastic rings at the feet and plumage colour spray (RAIDEX Animal Marking Spray®, RAIDEX GmbH, Dettingen/E., Germany). The body mass of the pigeons ranged from 0.36 - 0.45 kg. The birds were kept in 2 aviaries (aviary size 2.5 x 1.5 x 2.4 m) on a commercial diet for homing pigeons (vita-balance® Taubenfutter Universal, Meliofeed AG, Herzogbuchsee, Switzerland). Food and water was available ad libitum. Groups were arranged according to social interaction, with one control bird in each aviary. All birds tested negative for *Chlamydia psittaci* and *Salmonella* spp. They had been vaccinated by the breeder against *Paramyxovirus 1* (Nobilis® PARAMYXO P201, MSD Animal Health GmbH, Luzern, Switzerland). All pigeons were treated against trichomoniasis with dimetridazole (500 mg/l drinking water, Chevicol®, Chevita GmbH, Pfaffenhofen, Germany) for 6 days, once against ectoparasites with pyrethrum (Vinx nature Farmers Anti-Insect-Spray®, A. Ziegler AG, Stallikon, Switzerland) and coccidia with toltrazuril (75 mg/l drinking water Baycox®, Provet SA, Lyssach, Switzerland) for 5 days. Radiographic examinations of the wings were performed and revealed no abnormalities.

The manual skills necessary for the intended surgery were acquired by practicing on dead pigeons and in a preliminary trial with 4 animals intended for euthanasia.

Approximately 30 minutes prior to surgery, the pigeons received tramadol (5 mg/kg IM; Tramadol-Mepha®, Mepha Pharma AG, Aesch, Switzerland) and meloxicam (2 mg/kg IM; Metacam®, Boehringer Ingelheim GmbH, Basel, Switzerland). The pigeons were pre-medicated with ketamine (20 mg/kg IM; Ketanarkon®, Streuli Pharma AG, Uznach, Switzerland) and medetomidine (0.2 mg/kg IM; Dorbene®, Graeub AG, Bern, Switzerland). Anaesthesia was induced with 5% isoflurane (IsoFlo®, Aboot, Baar, Switzerland) in oxygen via facemask. Once anesthetized, the birds were intubated with a 20 or 25 AT sized uncuffed endotracheal tube (SurgiVet, Waukesha, USA) dependent on the size of the individual pigeon. The cornea were kept moist by covering with retinol palmitate eye ointment (Vitamin® A, Bausch & Lomb Swiss SA, Zug, Switzerland). An intravenous catheter was placed in the *Vena metatarsalis plantaris medialis* or the right *Vena ulnaris* and lactated Ringer's solution (Ringer-Acetat Fresenius®, Fresenius Kabi AG, Oberndorf, Switzerland) mixed equally with 5% glucose solution (Glucose 5% Fresenius®, Fresenius Kabi AG, Oberndorf, Switzerland) was administered at a rate of 10 ml/kg per hour during surgery. Patient monitoring included observation of reflexes, electrocardiography, auscultation of heart and respiration, body temperature and pulse-oxymetry.

Birds were placed sternally and the wings and the head were kept slightly elevated by positioning the patient in a U-shaped board that provided a stable background for drilling and sawing. The cover feathers of the left distal wing were plucked from the dorsal side of the antebrachium. The surgical site was aseptically prepared (Octenisan® and Kodan® forte farblos; Schülke & Mayr GmbH, Norderstedt, Germany) and covered with a sterile transparent plastic sheet (Plastic-tac®; Plasti-Pac Zürich AG, Obfelden, Switzerland). At the end of surgery, the pigeons received atipamezole (1 mg/kg IM, Alzane®, Graeub AG, Bern, Switzerland). In addition, doxycyclin (75 mg/kg IV, Vibravenös®, Pfister AG, Zürich, Switzerland) in 4 ml 0.9% sodium chloride solution (NaCl 0,9% B.Braun®, B.Braun Medical AG, Sempach, Switzerland) mixed equally with 5% glucose solution was administered during surgery.

Surgeries were performed in a randomized order of birds from the different groups. The surgeries of the 4 groups differed in the implant and the use of a figure-of-eight bandage. Birds in group A were treated with an eight-hole stainless steel adaption plate 1.3 (Synthes GmbH, Oberdorf, Switzerland) and 6 self-taping screws with a 1.3 mm thread diameter, 8 mm length, and 0.5 mm thread pitch. For drilling, a 1.0 mm drill bit was used with a mini air drill (Synthes GmbH, Oberdorf, Switzerland). In group B the same plate and screws were used, but additionally a figure-of-eight bandage was applied postoperatively for 10 days. The figure-of-eight bandage consisted of a non-adherent absorbent dressing (Telfa™, Covidien llc, Mansfiled, USA) applied directly on the suture, followed by a layer of synthetic orthopedic padding (Soffban® Synthetic, BSN medical GmbH, Hamburg, Germany) and covered by a stretched cohesive bandage (Vetrap™ Henry Schein INC., Melville, USA). Birds in group C were treated with a stainless steel compression plate 1.0 (Veterinary Instrumentation, Sheffield, UK) and 6 self-taping screws with 1.0 mm thread diameter, 8 mm length and 0.25 mm thread pitch. For drilling a 0.7 mm drill bit was used. This drill bit was bought at a hardware store, because surgical drill bits in this size were not available for the mini air drill used. In group D the same plate and screws were used, but additionally a figure-of-eight bandage was applied postoperatively for 10 days.

The general aspects of surgical procedure were according to the study of Christen et al.[1] and Gull et al.[2] A dorsal approach to the radius and ulna was used. The skin incision was made just cranial to the insertion point of the secondary flight feathers of the left ulna. The fractures were produced by transecting the diaphysis of the radius and the ulna with an oscillating bone saw (blade width 6 mm, thickness 0.25 mm) (Synthes GmbH, Oberdorf, Switzerland). The ulnar osteotomy was stabilized using one of the plate systems while the radius was not stabilized. The skin was closed with a single interrupted suture using 5-0 PDS*II (Ethicon GmbH, Norderstedt, Germany).

Following surgery, the birds had individual cage rest (cage size 0.6 x 0.6 x 0.4 m) for up to 14 days. The animals were handled as little as possible and only while being wrapped in a towel to minimize uncontrolled wing movements. Postoperative analgesia was provided with tramadol (5 mg/kg IM q12h; Tramadol-Mepha®, Mepha Pharma AG, Aesch, Switzerland) for 1 day and meloxicam (2 mg/kg PO q12h; Metacam®, Boehringer Ingelheim GmbH, Basel, Switzerland) for 5 days. If the bird did not receive intravenous doxycycline intra operationem as described above, oral doxycycline (250 mg/l drinking water; Streuli Pharma AG, Uznach, Switzerland) was administered for 7 days. If signs of pain were observed (such as fluffed up feathers in hunched posture, shivering slightly with the left wing), the application of analgesics was prolonged. Recovery food (12 ml PO BID, Avifood®, Harrison's Bird Foods, West Palm Beach FL, USA) was given in addition to the regular diet if a bird lost more than 10% of its body mass.

Figure-of-eight bandages in group B and D were changed after 3 days under general isoflurane anesthesia. The affected limb was carefully stretched to reduce the risk of shortening of the propatagium and the wound was disinfected (Octenisept® farblos/incolore, Schülke & Mayr GmbH, Norderstedt, Germany). Changes of bandage were repeated according to necessity, on average 2 (1 - 7) times per bird.

The position of the affected wing was noted every other day during cage rest and at day 10, 14 and 28 post-surgery. Mediolateral and caudocranial radiographic studies were taken from the wing 3, 14 and 28 days after surgery. For evaluation and measurements, the OsiriX Imaging Software (OsiriX Foundation, Geneva, Switzerland) was used. The length of radius and ulna, the step between the fracture margins of the ulna, and the maximal fracture gap were measured. The percentage of pigeons of a group in which all screws were bicortical was evaluated. Signs of osteomyelitis (bone lucency, irregular fracture margins, periosteal reactions), the occurrence of synostosis, loosening of screws or additional fractures were noted. The angle of the fracture ends of the ulna was measured at the intersection of a line from the distal metaphyseal corticalis of the ulna to the distal corticalis of the osteotomy site, and a line from the corticalis of the osteotomy site to the metaphyseal corticalis of the proximal ulna. The alignment of the fracture ends of the radius and the ulna was evaluated. The width of the mineralized callus, classified as maximal callus width, was measured at the caudal surface of the ulna and radius at the fracture site. The bone width was measured at the distal end of the ulna and radius, classified as distal bone width. The ratio of the maximal callus width to the distal bone width was calculated and recorded as callus ratio.

Flight ability was assessed by two methods. At least twice daily, the birds in the aviaries were checked and it was noted if a pigeon perched in the upper half of the aviary (at 110 - 240 cm) that had not been seen there before. In addition, two cameras (DAY&NIGHT COLOR CCD CAMERA 3.6mm lens, Visor Tech®, PEARL GmbH, Buggingen, Germany) linked to a video recorder (D7704HT, Visor Tech®, PEARL GmbH, Buggingen, Germany) were installed in each aviary, one pointing at the feeding/drinking station at 110 cm height and the ground, the other pointing at the upper perches. Flight ability at day 14, 21 and 28 days post-surgery was classified into 4 categories: very good flight ability equal to physiologic flight ability of the control animals (no problems reaching perches located at a height of 220 cm), good flight ability (no problems reaching perches located at 200 cm), moderate flight ability (no problems reaching perches located at 30 – 110 cm), and poor flight ability (not reaching a height of 30 cm).

Twenty-eight days after surgery the pigeons were anesthesized with ketamine (25 - 30 mg/kg IM; Ketanarkon®, Streuli Pharma AG, Uznach, Switzerland) and medetomidine (0.25 - 0.30 mg/kg IM; Dorbene®, Graeub AG, Bern, Switzerland) and euthanized with pentobarbital (750 mg/kg IV; Eskonarkon®, Streuli Pharma AG, Uznach, Switzerland). The treated wings were dissected and signs of distortion and bending of the plate, osteomyelitis, and the callus formation were noted.

Groups were compared by one-way ANOVA with Sidak post hoc tests if measurements had normal distribution, and by Kruskal-Wallis-test and subsequent pair-wise Mann-Whitney U-tests (with Sidak adjustment for multiple testing) if not. All analyses were performed in SPSS 21.0 (SPSS Inc. Chicago, IL). Significance was set at 0.05.

Results

In the subjective opinion of the surgeon (B.B.) the surgical technique differed only minimally between the plate systems, but the ease in plate application was not similar. As the tip of the 1.0 mm cruciate screwdriver has a taper fit that holds the screw without a sleeve, the screws used to install the compression plate 1.0 were prone to fall off the screwdriver. Despite this, mean anesthesia duration (87.2 ± 14.9 min) did not differ significantly between groups ($F_{3, 23} = 0.341$, $P = .796$). The mean surgery duration (51.7 ± 12.0 min) did not differ significantly between groups ($F_{3, 23} = 1.022$, $P = .401$), either (Tab. 1).

Several difficulties occurred during surgery (Tab.1). In 1 pigeon from group B an axis deviation of 1 screw resulted in fracturing of the ulna, and 4 instead of 6 screws were used in this animal. In group A and C, screw holes needed to be redrilled in 5 animals following application of the plate (in group A:1, C:4). In 3 pigeons (1 each in group B, C, D) the position order of 1 screw each had to be changed.

Post-surgery, in 3 of the birds accidental fractures of the ulna occurred. One pigeon each of group A and group C needed to be euthanatized because they suffered from comminuted fractures due to wing flapping during handling. One bird in group C fell on the left wing during recovery from anesthesia. As it had a monocortical stable fracture, it remained participant of the study. One pigeon in group A developed instability of the ulna and required prolonged cage rest until day 14 after surgery. By 28 days after surgery, the fractures of all remaining birds were stable at palpation of the wing. Three pigeons (in group B:1, C:1, D:1) showed depression and anorexia post-surgery and were housed separately for a prolonged period and their flight ability was not evaluated on the corresponding date.

Radiological evaluation (Fig. 1 – 4, Tab. 2) revealed no signs of plate bending or screw loosening. All screws remained bicortical until the end of the study except for 1 screw each in 1 pigeon of group B and D. The pigeon in group B was the bird that suffered from a committed fracture during surgery. In this bird, 1 screw was unicortical at radiographs taken 14 days after surgery and remained in that position until the end of the study. The screws of the pigeon in group D were bicortical including all radiographs taken before 28 days post-surgery, but 1 screw was unicortical at the radiographs 28 days post-surgery. The wings of these birds were stable on palpation.

Results of radiographic measurements are summarized in Table 2. The only significant radiographic difference between groups was regarding maximal callus width of the radius. Pigeons of group A (5.9 ± 0.9 mm) and C (5.8 ± 0.8 mm) showed significantly less maximal callus width of the radius (Kruskal-Wallis-test, $P = .034$) than those of group B (7.1 ± 1.0) and D (6.8 ± 0.6) on radiographs taken 28 days post-surgery. The callus ratio of the ulna did not differ between groups but the mean ratio in all animals (2.04 ± 0.43) was significantly smaller than that of the radius (2.42 ± 0.49; paired t-test t = 3.782, P = .001, n = 25).

The length of the ulna (pre OP 59.5 ± 2.2mm) remained unchanged (3 days post OP 59.1 ± 2.2 mm), whereas the length of the unfixed radius was reduced by 2.0 mm to 51.3 ± 1.8 mm at 28 days after surgery, as the radial fracture ends were dislocated in the majority of animals (in group A:4, B:4, C:5, D:5).

In 8 pigeons (29,6%) postoperative signs of fractures or fissures occurred (in group A:2, B:2, C:3, D:1). This led to the euthanasia of 2 animals (1 pigeon each in group A and C) for humane reasons as mentioned earlier. The cage rest of the other animals was prolonged until 14 days post-surgery, but no further treatment was needed. The wings of these birds were stable on palpation. Radiographically, 1 bird of group A showed signs of osteomyelitis and 1 bird of group D showed the development of a synostosis between radius and ulna.

Thirteen pigeons (group B:6, D:7) were treated with a figure-of-eight bandage. It was noted that the position of the left wing did differ significantly at day 10 post-surgery (Kruskal-Wallis-test, P = .041) in group C compared to group D. The wing tip of pigeons of group D touched the ground or the pigeons let their left wing droop mildly without the wing tip touching the ground whereas pigeons of group C held their wings in physiologic position or let their left wing droop mildly without the wing tip touching the ground. However, this difference was no longer evident at 14 days or 28 days after surgery, when most of the pigeons showed only a slight drop of the wing without the wing tip touching the ground, or held the wing in physiologic position. There was no correlation between slight wing drop or physiologic wing position and flight ability.

Evaluation of flight ability on day 28 post-surgery in 23 birds (group A: 6, B: 5, C: 5, D: 7) is represented in Table 1 and 3. There were no significant differences in flight ability between the treatment groups at any time point. Most pigeons began to flap their wings and fly short distances in the lower half of the aviaries at 14 days post-surgery and regained good to very good flight ability between 21 and 28 days post-surgery. The combination of both methods assessing flight ability (personal observation and video observation) allowed defining the mean number of days when the pigeons were seen in the upper half of the aviary for the first time (21.7 (± 5.9) days post-surgery), respectively (Tab. 3). It is also interesting to note that results gained by camera observation differed from those gained during approaching/handling of the birds at 28 days post-surgery (Tab. 1): In presence of a human, 12 and 11 birds showed very good and good flight ability, respectively.

At necropsy evaluation, no significant differences among the treatment groups were found. The bones of 3 pigeons showed signs of osteomyelitis (in group A:1, C:2). In 7 birds, the implant was still visible (in group B:2, C:2, D:3), in 15 birds, the plate and screws were only partially visible (in group A:6, B:4, C:2 D:3), and in 3 birds, no implant was visible due to the callus formation (in group C:2, D:1). In one pigeon of group D, the synostosis diagnosed by radiography was confirmed.

Discussion

In this study, we evaluated 2 different miniplates, with and without use of a figure-of-eight bandage post operatively for birds weighing less than 500 g. Taking into account the results described above, there was, in contrast to our predictions, no significant difference between the treatment groups. There was no evidence that fracture healing with less callus proliferation and better ability of flight could be achieved using a 1.0 compression plate compared to a 1.3 adaptation plate. The use of a figure-of-eight bandage post operatively for 10 days did not improve fracture healing.

In contrast to similar studies,[1, 8] there was neither distortion nor bending of the plates in the present study (Fig. 5). This finding is explained by the material of the different plate systems.

The maxillofacial miniplate compact 1.0 with 11 holes evaluated by Gull et al.[2] consisted of titanium, whereas the adaption plate 1.3 as well as the compression plate 1.0 evaluated in the present study consisted of stainless steel. Taking into account the results of all studies[1, 2] evaluating these plates for their applicability for wing fracture repair, we conclude that stainless steel plates are required to withhold the in vivo stresses for fracture repair of the ulna in pigeons. Stainless steel plates as implanted in the present study are suited for single plating of fractures of the avian antebrachium. With respect to plate choice it should be noted that the compression plate system used in this study provides fracture fixation with equal clinical results at an economically preferable prize in comparison with the adaption plate system.

An additional finding of this paper is regarding the importance of screw length.

In the study performed by Gull et al.[2] 1 experimental group of 6 pigeons (group A) was treated with an eight hole adaption plate 1.3 using 4 screws of 6 mm length. In our study in group A the same plate with 6 screws with 8 mm length were used. In the study of Gull et al.[2] 1 out of 6 pigeons had to be euthanatized due to screw loosening and 3 out of 6 pigeons had screws which were not bicortical. In the present study in contrast, screw loosening was only observed in 1 out of 7 pigeons in the corresponding treatment group. The choice of longer screws is recommended to ensure bicortical placement. This is especially critical when performing surgery in small animals as no deep gauge is available for such small implants which would allow measuring the length of the screw holes intra surgery.

In contrast to the predictions of Gull et al.[2] thread pitch of screws was not as critical as screw length. In this study screws with a thread pitch of 0.25 and 0.5 mm were used. Gull et al.[2] suggested that the use of screws with a thread pitch of less than 0.5 mm may be preferable due to better holding power. However, in the present study no signs of a difference in holding power were observed. Nevertheless, the screws with a thread pitch of 0.25 mm may prove to be advantageous in birds with a thinner cortex than the ones used in this study.

The surgery time in this study was comparable to the study by Gull et al. [2] The mean surgery time in the present study was increased by 15 minutes, which is explained by the fact that two more screws were applied. These additional screws seem to have had an effect on fracture stability and facture healing, which resulted in less callus formation. The comparison of the 4 experimental groups of the present study with group A of Gull et al.[2] with respect to the ulnar callus ratio at 28 days after surgery (Fig. 6) reveals that there was a significant difference between the treatments (ANOVA $F_{4,25}$ = 4.210, P = .010). Sidak post hoc tests revealed significant differences between group A of Gull et al.[2] (3.41 ± 1.47) and groups B (2.09 ± 0.12), C (1.78 ± 0.62) and D (2.10 ± 0.45) of the present study. Avian fractures heal with the same physiological processes taking place as in mammals but more quickly and callus formation appears to be similar in birds and mammals.[9, 10] First bridging occurs in the periphery in the callus, where tissue strain is the lowest.[11] The more interfragmentary motion occurs due to instability of the chosen fixation of the fracture, the more callus is formed at the fracture side.[11] Therefore it is not surprising that the callus ratio of the unfixated radius of all pigeons at 28 days post-surgery was significantly larger (2.4 ± 0.5) than that of the fixated ulna (2.0 ± 0.4; t = 3.782; P = .001) of all pigeons (also see Fig. 1 – 4).

If removal of an implant is recommended (e.g. in birds intended for release in the wild) this study offers information regarding the time-point. At day 28 after surgery in 15 birds the plate was only partially visible and in 3 birds the plate was completely covered by callus. In these birds plate removal would have been very challenging if not impossible. We therefore conclude that implant removal is recommended earlier than day 28 after surgery with the plate systems used in this study.

The use of a figure-of-eight bandage did not result in a significant difference regarding speed of healing and callus formation. The more pronounced wing droop shown by the birds of group D at 10 days after surgery was resolved by day 14 after surgery. In addition, these pigeons showed no statistically relevant impairment in their flight ability.

Therefore one may deduct that the use of a figure-of-eight bandage does not bring any advantages. Nevertheless we consider the application of a figure-of-eight bandage to be an advantage and we found two reasons for it.

At necropsy signs of osteomyelitis were only found in groups treated without bandage. This finding might indicate that the application of dressings is advantageous to reduce the risk of infection and the development of bacterial osteomyelitis.

The figure-of-eight bandage may also have reduced the risk of fracture occurrence after surgery. No bird of group B and D suffered from additional fractures due to wing flapping while handling or recovery from anesthesia, whereas two birds treated without bandage needed to be euthanized because of additional fractures.

Therefore the authors do recommend the use of a figure-of-eight bandage post-surgery for up to 10 days. The bandage should be changed every 2 to 3 days for inspection of the wound. Bandage changes should also be used to perform physical therapy as described by Wimsatt et al.[12] to prevent complications from immobilization such as muscle atrophy, joint ankylosis, tendon contraction, and patagial constriction. In the present study, the wings were very gently stretched and mobilized during bandage changes.

Regarding the radiographic diagnosis of osteomyelitis this study revealed that radiography only detected osteomyelitis in 1 out of 3 birds. This finding emphasizes the fact that it may take days or weeks until bacterial osteomyelitis becomes evident with plain radiography.[13]

In the post-surgical radiographic examinations 29.6% of the pigeons of our study showed fissures or fracture lines. Fissures may occur intraoperatively during manipulation with surgical equipment and implant. As the avian bone with its specific structure is more prone to brittle than a mammalian bone, one may easily damage the thin avian corticalis while placing the screws or pins.[9, 14-16] Post-surgery, suboptimal placement of the implant may result in too high strain on the bone due to wrong positioning or wrong size of the implant. A recently stabilized bone may fracture due to a trauma in the recovery and reconvalescence period as described for the 4 birds mentioned earlier. Unnoticed trauma due to too much pressure on the stabilized bone post-surgery, maybe during handling, cannot be ruled out completely for the 4 remaining pigeons but seemed less likely. As a limitation of the study the first X-rays postoperatively were not taken immediately after, but at 3 days post-surgery, thus these possible reasons could not be definitely narrowed down further.

The occurrence of iatrogenic fracture formation as a result of pin insertion was reported by Ferraz et al.[17] In that study, 18 experimental induced distal fractures of the humerus of 12 pigeons were stabilized with an articulated external fixator consisting of 3 titanium-rods with 6 mm diameter and 5 (3 humeral placed / 2 ulnar placed) Shunz Pins with 1 mm or 1.5 mm diameter. Iatrogenic fractures of humerus and/or ulna occurred in 33.3% of osteotomies during insertion of the pins. The authors concluded the large pin size to be the most likely cause for the iatrogenic fractures. This could be the case in present study as well, as the ulnar diameter did vary according to the size of the individual pigeon.

Comparing the results in regard to flight ability of that study[17] with the present study is interesting, too, as the study design in that aspect is similar. Ferraz et al.[17] state adequate flight capacity in all 6 birds by at least 13 weeks post-surgery, 2 weeks after being put in aviaries (2.5 m x 2.5 m x 3 m) allowing unrestricted movement. In the present study, the mean of days for all pigeons evaluated for their flight ability to regain good flight ability is 21.8 (± 4.4) days post-surgery, 11.8 (± 4.4) days after being put in aviaries allowing unrestricted movement.

The 2 methods to evaluate flight ability in the present study yielded different results, direct observation scored birds in better flight ability than camera observation. This may reflect the tendency of birds to hide a weakened condition in sight of a possible threat as the sight of humans approaching, even though the pigeons used were raised as companion animals.

These differences would possibly be even more distinct in a wild animal with no possibility to get familiar with the housing and might confuse the clinical assessment of the patient, thus provoking a premature release. This discrepancy could be surely minimized by examination without human input, i.e. the installation of cameras in the aviaries in question, thereby reducing the influence of stress on the evaluated behaviour.

Conclusion

The present data suggest that stainless steel miniplate systems are suitable for ulna fracture repair in birds weighing less than 500 g using screws with a thread pitch of either 0.25 mm or 0.5 mm. If plates are to be removed, this must be done before day 28 after surgery. The use of a post-surgical figure-of-eight bandage for up to 10 days may be advantageous, and appears to reduce the risk of postoperative wound infection. When evaluating flight ability it should be noted that birds may feign better ability. This is of special importance in birds which are not accustomed to humans.

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Figure 1 Two-view radiographs of a pigeon in group A (adaption plate 1.3) (a) 3 days after ulnar surgery, (b) 14 days after surgery, and (c) 28 days after surgery.

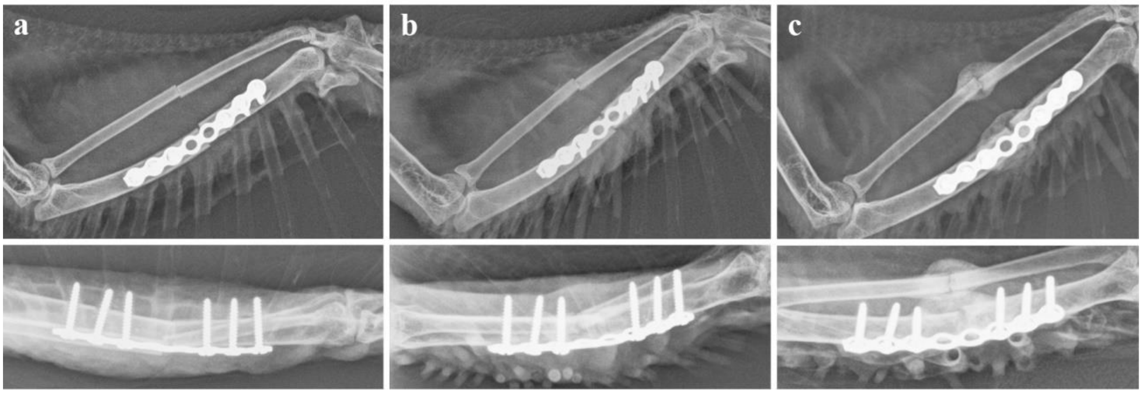


Figure 2 Two-view radiographs of a pigeon in group B (adaption plate 1.3 and figure-of-eight bandage) (a) 3 days after ulnar surgery, (b) 14 days after surgery, and (c) 28 days after surgery.

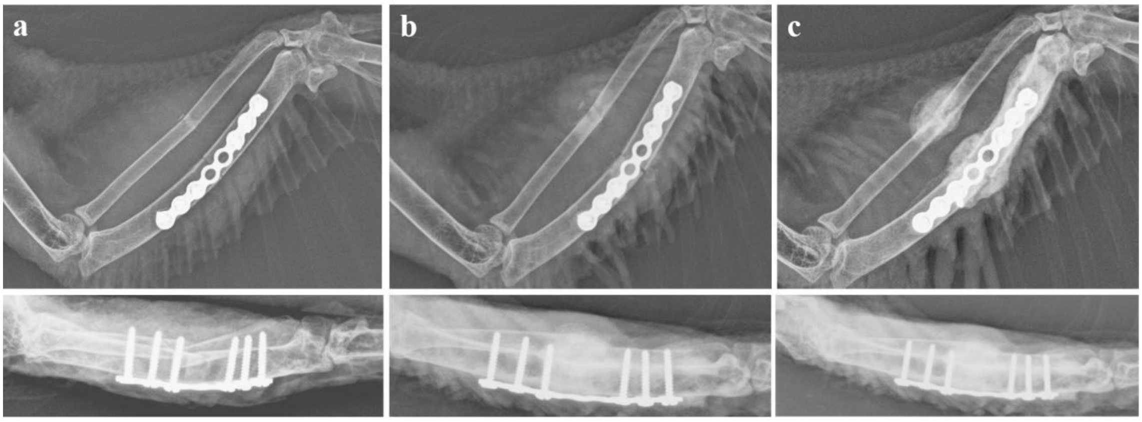


Figure 3 Two-view radiographs of a pigeon in group C (compression plate 1.0) (a) 3 days after ulnar surgery, (b) 14 days after surgery, and (c) 28 days after surgery.

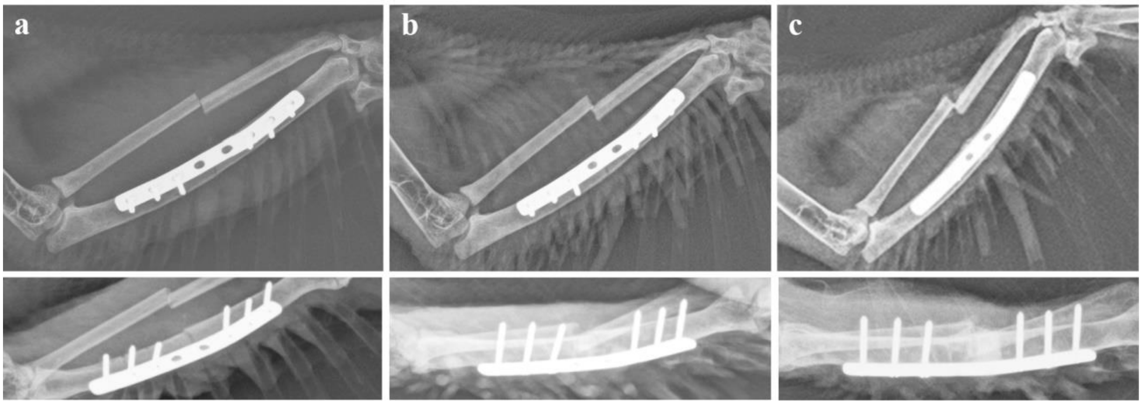


Figure 4 Two-view radiographs of a pigeon in group C (compression plate 1.0 and figure-of-eight bandage) (a) 3 days after ulnar surgery, (b) 14 days after surgery, and (c) 28 days after surgery.

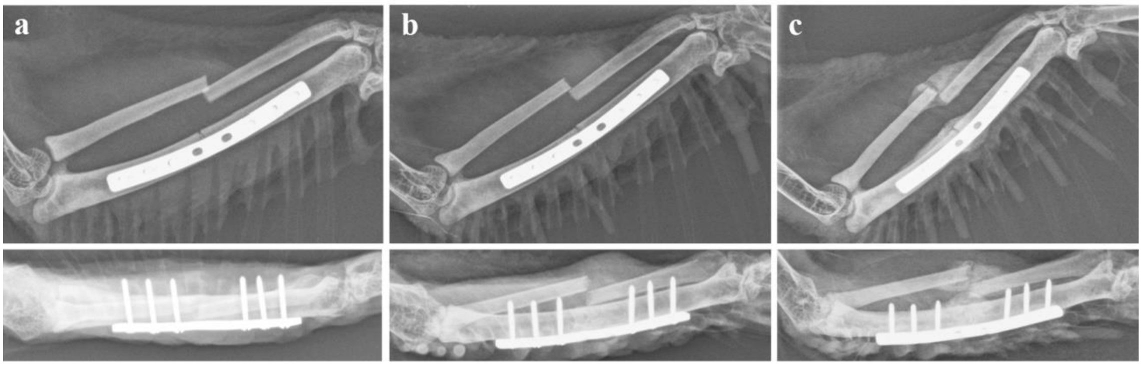


Figure 5 Mean angle of osteotomy ends of the ulna measured in pigeons immediately after surgery (osteotomy of ulna and radius, fixation of ulna) and/or at 3, 14 and 28 days later. Note that in contrast to group C of Gull et al. (2012)[2], treated with a titanium miniplate, the steel plate systems used in both studies showed no evidence of bending irrespective of number of screws or additional bandaging after surgery.

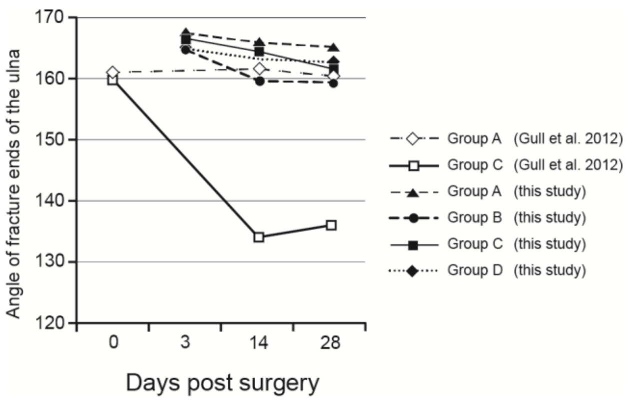
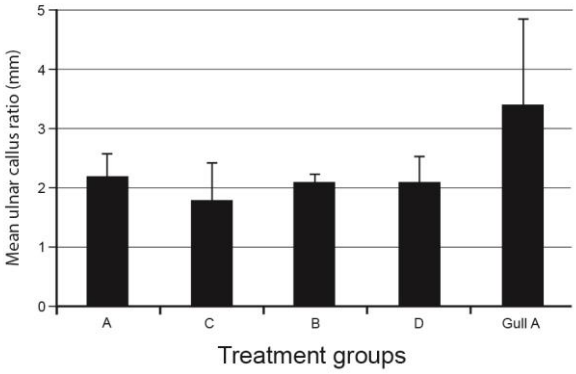


Figure 6 Mean ulnar callus ratio measured in pigeons (osteotomy of ulna and radius, fixation of ulna) 28 days post-surgery. There were significant differences between group A of Gull et al. (2012)[2] and groups B, C and D of the present study due to the increased number of screws applied.



Mean ulnar callus ratio (mm)
5
4
3
2
1
0
A
C
B
D
Gull A
Treatment groups

Table 1 In 4 groups of pigeons (A: n=7, B: n=6, C: n=7, D: n=7) fractures of the radius and the ulna were induced, and the ulna was repaired with a bone plate (Ap = adaption plate 1.3 or Cp = compression plate 1.0) and with a figure-of-eight bandage (+) or without (-). The most important findings and differences between the groups A, B, C, and D are listed. No statistically significant differences were measured between the groups.

Parameter	Days after surgery	Group A Ap -	Group B Ap+	Group C Cp-	Group D Cp+
Surgical time (mean ± SD), min	-	50.6 ± 6.7	43.9 ± 4.8	56.7 ± 16.5	53.1 ± 15.2
Surgical procedure: **Problems**	-	Redrill of holes necessary, soft tissue trauma	Accidental fracture while inserting 1 screw, variation in order of screws	Redrill of holes necessary, variation in order of screws	Soft tissue trauma, variation in order of screws
Euthanized because of screw loosening, %	1 until 28	0	0	0	0
Euthanized because of fracture, %	1 until 28	14	0	14	0
Plate bent and twisted, %	14	0	0	0	0
	28	0	0	0	0

Callus width (mean ± SD), mm	14	Signs of bone remodelling, but not measurable			
	28	9.5 ± 1.9	9.6 ± 0.5	7.9 ± 2.6	9.4 ± 1.6
Flight ability, %[1]					
very good	28	**43** / 71	**17** / 17	**14** / 43	**14** / 43
good	28	**29** / 14	**50** / 67	**14** / 29	**14** / 57
moderate	28	**0** / 0	**17** / 0	**29** / 0	**43** / 0
poor	28	**14** / 0	**0** / 0	**14**/ 0	**29** / 0
not evaluted	28	**14** / 14	**17** / 17	**29** / 29	**0** / 0
Signs of osteomyelitis at necropsy, %	28	14	0	29	0

[1]Observations gained by **video observation** / direct observation in 23 pigeons, not evaluated refers to pigeons euthanized for humane reasons or housed outside aviaries.

Table 2 Mean radiographic values from 4 groups of pigeons (A: n=7, B: n=6, C: n=7, D: n=7) following experimental fracture of the radius and the ulna.

	Days after surgery	mean (±SD)
Length of radius, mm	0	53.3 (± 2.2)[a]
	3	50.5 (± 2.2)[b]
	28	51.3 (± 1.8)[c]
Length of ulna, mm	0	59.5 (± 2.2)
	3	59.1 (± 2.2)

	28	59.5 (± 1.8)
Maximal fracture gap of the ulna, mm	3	0.2 (± 0.17)
Step between the fracture margins of the ulna, mm	28	0.6 (± 0.7)
Angle of the fracture ends of the ulna, degree	3	165.9 (± 4.7)
	14	163.6 (± 4.9)
	28	162.6 (± 4.9)
Callus ratio ulna	28	2.0 (± 0.4)
Callus ratio radius	28	2.4 (± 0.5)

a,b,c different superscripts indicate significant differences (paired t-test with Sidak adjustment) in the length of the radius; there were no significant differences in the length of the ulna

Table 3 Mean (±SD) number of days following experimental fracture of the radius and the ulna at which pigeons were first seen in the upper half of the aviary.

Group	**Good flight ability**		**Very good flight ability**	
	mean (d)	% of pigeons	mean (d)	% of pigeons
A	19.9 (± 4.4)	100	23.6 (± 4.4)	83.3
B	21.2 (± 1.1)	83.3	24.5 (± 4.9)	40
C	22.4 (± 4.0)	83.3	25.7 (± 2.5)	60
D	23.4 (± 6.1)	100	25.0 (± 5.2)	42.9

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